4. Conclusions

The data collected in this study point to a gradual recovery of benthic invertebrates in Silver Bow Creek. It appears that the combination of mining and municipal wastes discharged into the headwaters of Silver Bow Creek over the last 100 yr had a devastating effect on the invertebrate community. No organisms were collected in the stream from 1972 through 1974 and it is unlikely that invertebrates were present in the creek immediately prior to 1972. This community is only now beginning to recover, over 10 yr after initiation of improved mine wastewater treatment. Although densities in Silver Bow Creek have increased over the years, the results still indicate a stressed invertebrate community. The delayed recovery at the upstream stations may have initially been a result of the stress of high pH rather than metals. Nonetheless, the lack of more significant recovery despite improved water quality is surprising and may relate to the lack of reliable upstream source of invertebrate colonizers. In fact, the earlier recovery at the downstream Stations 4 and 5 is probably attributable to colonization by drifting invertebrates from tributary streams and aerial colonization from populations in Mill and Willow Creek.

The lack of a full recovery in Silver Bow Creek does not appear to be due to poor habitat, especially at the downstream stations and may relate to presently undetermined amounts of metals still present in the substrate of streambanks.

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LEACHABLE AND TOTAL PHOSPHOROUS IN URBAN STREET TREE LEAVES

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Abstract. Urban runoff contains large quantities of a variety of pollutants, including P but there have been few descriptions of the sources of these pollutants. An average of 148 μg gm^{-1} (air-dried weight) of P was leachable from entire leaves in 2 hr: this represented 9.3% of the total P available. The amount of leachable and total leaf P varied significantly among tree species but was not affected by tree diameter. These results point to a possible important source of urban runoff P.

1. Introduction

Urban runoff contains a wide variety of nutrients, heavy metals, synthetic organic chemicals and sediments (Whipple *et al.*, 1978). Urban runoff has been cited as the main source of lake P in Madison, WI (Kluesner and Lee, 1974) and in Minneapolis, MN (Shapiro and Pfannkuch, 1974). Sources of this P have not been examined in detail but include automobile exhaust, lawn fertilizers, atmospheric deposition and tree leaves. For instance, in a study of P loading to a suburban lake in Illinois, vegetation contributed 54%, fertilizer 27% and animals 14% of the total P in the watershed (N.E. Illinois Planning Commission, 1983). No estimate of leachable P pools was made.

Kelling and Peterson (1975) found that very little P was lost from fertilizer when applied to residential lawns. In contrast, Halverson *et al.* (1984) found that rain falling through an urban tree canopy (*Acer negundo* L.) had enhanced concentrations of several elements, including P (ratio of P in throughfall to precipitation was 100 : 1). Similar findings have been reported in natural ecosystems. For instance, in an oak-hickory forest in rural Illinois, both water-related P pathways and litterfall contributed equal amounts of P (Rolfe *et al.*, 1978). Tree leaves present a large surface area for collection of elements through dry fallout. For instance, Dorney *et al.* (1984) found that tree canopies covered about 39% of a residential area. Similarly, tree canopies were reported to occupy about 1/3 of the area of an older suburb in Illinois (N.E. Illinois Planning Commission, 1983). Trees also transport elements from soil to leaves where the elements are subject to leaching and eventual transport to urban surfaces. Therefore, the contribution of P from leaf fall and leaching may be important in urban areas.

Concentrations of total P in tree leaves have been widely reported for various natural ecosystems (Mitchell, 1937; Huzalak, 1973). In a study of leaf leaching from forest trees, Gosz *et al.* (1975) reported substantial amounts of Ca, Mg, K, Na, and total N leached from leaves of several species. Maximum amounts were leached after leaf abscission. In urban areas, only Cowen and Lee (1973) have examined leachable tree leaf P using

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oak (*Quercus* sp.) and poplar (*Populus* sp.) leaves in Madison, WI. They found that poplar leaves had higher levels of leachable P than oak leaves (140 $\mu g\ L^{-1}$ vs 84 $\mu g\ L^{-1}$, respectively). The amount of P leached increased with leaching time and leaf fragmentation. The N.E. Illinois Planning Commission (1983) reported that maple leaves (*Acer* sp.) contained 0.14% total P.

This research was conducted to determine the content and variability of P in urban street tree leaves. Specific goals were to determine (1) the amount of P leachable from tree leaves in 2 hr in distilled water, (2) total leaf P content, (3) differences among species in total and leachable P, and (4) the effect of tree diameter on leaf P levels. This represents the first step in determining the importance of urban street tree leaves as a P source in urban runoff.

2. Methods

Freshly fallen, dry tree leaves and seeds were collected from 52 Milwaukee and Shorewood, WI (an adjacent suburb) residential street trees (representing 13 species) in September and October 1978. Leaves were collected after they had fallen but before they were washed by significant (> 0.5 cm) rainfall. Tree species, diameter at breast height, and location were noted. Leaves and seeds were air-dried at approximately 21 °C for at least 2 weeks.

Analysis of leachable P was modified from the method of Cowen and Lee (1973). Samples of entire leaves were weighed, placed in acid-washed 1.2 L glass cylinders, and 1 L of distilled water was added. The leaves were soaked for 2 hr to simulate contact time with urban runoff. The liquid was poured off and leaves washed with an additional liter of water. Total leachable P in the water was determined using persulfate digestion followed by abscorbic acid determination with a Spectronic 20 spectrophotometer (American Public Health Association, 1976). Calibration curves were prepared daily using distilled water and prepared standards of 0, 2.5, 10, and 50 $\mu g\ L^{-1}$. Using the levels of total P in the water and calibration curves, the amount of leachable P per gram of air-dried leaf tissue was determined. Duplicate leachate samples were analyzed and, if results differed by more than 10%, additional leaves were leached. Duplicate portions of selected leaves were ground in a Wiley mill and sent to the University of Wisconsin-Madison Plant and Soil Testing Lab for determination of total leaf P.

Data were analyzed statistically using the SAS General Linear Models program to determine significant effects of species or tree size on leaf P (SAS, 1979). The Least Significant Difference (L.S.D. at $p \leq 0.05$) was used to determine significant differences between tree species.

3. Results

Concentrations of leachable P from intact tree leaves ranged from 20.1 to 410.8 $\mu g\ gm^{-1}$ air-dry weight with averages ranging from 38.1 to 259.9 $\mu g\ gm^{-1}$ (Table I). Leaves averaged 148.1 $\mu g\ gm^{-1}$ of leachable P. These levels are comparable to those reported by Cowen and Lee (1973). Total tree leaf P (average) ranged from 0.08 to 0.44% (Table I) and averaged 0.22% for all species. Only a small fraction of the total leaf P (average 9.3%) was leachable in the 2 hr test time.

TABLE I

Leachable P, total P and % of total P leachable (and standard deviation) from urban street tree leaves and seeds

Species name		Leachable P	Total P	% of total P leachable	Number of samples	
Common name	Scientific name	$\mu g\ gm^{-1}$	%		Leachable P	Total P
Leaves						
Sugar Maple	Acer saccharum Marsh.	259.9(113.1)	0.20(0.032)	13.43(6.2)	6	3
Silver Maple	Acer saccharinum L.	232.7(117.6)	0.13(0.040)	17.7(6.3)	3	3
Green Ash	Fraxinus pensylvanica Fern.	188.4(75.1)	0.24(0.049)	7.0(0.43)	7	2
Honey Locust	Gleditsia tricanthos L.	176.0(101.1)	0.44(0.117)	4.5(2.3)	8	5
White Ash	Fraxinus americana L.	161.9(137.9)	0.14(0.042)	9.6(0.04)	4	2
American Elm	Ulmus americana L.	158.5(66.8)	n.d.[b]	n.d.	2	0
Basswood	Tilia americana L.	95.7(32.1)	0.15(0.045)	7.8(2.1)	5	3
Chinese Elm	Ulmus pumila L.	88.6(36.1)	n.d.	n.d.	2	0
Little Leaf Linden	Tilia cordata L.	86.5(22.5)	0.09 (n.d.)	6.7(n.d.)	3	1
Pin Oak	Quercus palustris Muenchh.	81.5(29.3)	n.d.	n.d.	2	0
Norway Maple	Acer platanoides L.	80.1(53.9)	0.08(0.035)	8.4(3.63)	5	2
Hessian Ash	Fraxinus excelsior L.	66.1(40.0)	n.d.	n.d.	3	0
Weeping Willow	Salix babylonica L.	38.1(1.1)	n.d.	n.d.	2	0
All Leaves		148.1(99.4)	0.22(0.147)	9.3(5.4)	52	21
LSD[a]		38.8	0.06	3.4		
Seeds						
Green Ash	Fraxinus pensylvania Fern.	77.6(n.d.)	0.26(n.d.)	3.0(n.d.)	1	1
Sugar Maple	Acer saccharum Marsh.	40.8(12.5)	0.35(n.d.)	1.4(n.d.)	2	1
Little Leaf Linden	Tilia cordata L.	39.2(11.6)	0.26(n.d.)	1.8(n.d.)	2	1
All Seeds		47.5(18.9)	0.29(0.052)	2.1(0.8)	5	3

[a] Least significant difference ($P \leq 0.05$).
[b] n.d. = not determined.

Seeds from three tree species were also leached. In general, leachable P levels and percent of total P which was leachable were lower in tree seeds that in leaves, while total P was higher (Table I). Seeds are probably not important sources of leachable P; this is not surprising since tree seeds are designed to preserve their nutrients for germination.

Tree diameter did not have a significant effect on total or leachable P (at $p \leq 0.05$). However, levels of leachable ($p = 0.01$, $F = 2.59$), total ($p = 0.003$, $F = 9.59$) and percent of total P leachable ($p = 0.03$, $F = 3.46$) did vary significantly among species. Leaves from sugar maple (*Acer saccharum*), silver maple (*Acer saccharinum*) and green ash (*Fraxinus pensylvanica*) had significantly more leachable P than average while Norway maple (*Acer platanoides*), Hessian ash (*Fraxinus excelsior*), pin oak (*Quercus palustris*), weeping willow (*Salix babylonica*), basswood (*Tilia americana*), little leaf linden (*Tilia cordata*), and Chinese elm (*Ulmus pumila*) had significantly less. Total

P levels in tree leaves showed a different pattern with honey locust (*Gleditsia tricanthos*) having significantly higher levels while Norway and silver maple, white ash (*Fraxinus americana*), basswood and little leaf linden had significantly less. For the percent of total P which was leachable, only sugar and silver maple had significantly higher levels than average while honey locust had significantly less.

4. Conclusions

Other than the 1973 report by Cowen and Lee, there are no published data on urban tree leaf P levels. Urban maple trees in an Illinois study had 0.14% total P which is similar to this study (N.E. Illinois Planning Commission, 1983). Comparisons of total P in urban street tree leaves with similar species from natural environments show, in general, that urban trees appear to have levels of total P similar to trees in natural ecosystems. For instance, Henry (1973) reported total P contents of leaves from Minnesota forests of 0.18 to 0.30% for sugar maple (0.20% in this study), 0.22 to 0.37% for green ash (0.24% here) and 0.18 to 0.31 for basswood (0.15 here). Similarly, Chandler (1941) in hardwood forests in central New York state reported total P for leaves from 0.12 to 0.15% for sugar maple (0.20% here), 0.15 to 0.16% for white ash (0.14% in this study) and 0.14 to 0.17% for basswood (0.15% here).

It is apparent that urban street trees contain relatively high amounts of total P and that only a small fraction (about 9%) is readily leached from entire leaves in 2 hr. However, leaves often remain on streets for many days and may be subject to numerous rainfall events. It is unclear to what extent repeated leaching (which more closely reflects periodic rainfall-runoff events) and leaf fragmentation (which occurs as the leaves weather *in-situ*) would increase leachable P. Certainly, high levels of P remained in these leaves after 2 hr of leaching. In addition, these leaves were leached in distilled water. In urban areas, rainfall is likely to be acidic and contain various dissolved substances (Betson, 1978). Leaching rates may be different with urban rainfall. Finally, leaf leaching and washoff of P will occur throughout the year and could introduce nutrients to urban runoff in addition to those nutrients from leaf fall and subsequent leaching.

Street tree planting and leaf pickup policy in most, if not all, cities does not take into account the importance of leaves as a source of urban runoff pollutants, including P. Street trees in Milwaukee, WI (as in other cities) are mostly chosen on the basis of tree availability, tolerance to urban microclimates, disease resistance, growth form and growth rate (Skiera, 1978).

Whether urban street trees are a significant source of P in urban runoff is uncertain. Levels of total P in urban runoff vary greatly with time. However, in at least three studies (Shapiro and Pfannkuch, 1973 in Minneapolis, MN; and Kluesner and Lee, 1974 in Madison, WI; Weatherbe and Novak, 1977 in Toronto, Ontario) largest peaks of total P in urban runoff occurred in Fall (September to November) or late Spring (April to May). These levels may be associated with leaf fall and tree flower fall, respectively. Further research is warranted especially into the effects of repeated leaching events, leaf fragmentation, P content of tree flowers and differences among species.

It is apparent that urban street tree leaves contain fairly high levels of total P, a portion of which is readily leachable and could contribute to P from urban runoff. In the absence of further data, it would be prudent to collect for disposal urban street tree leaves as rapidly as possible, not to store them (before collection) on impervious surfaces and to collect leaves in areas dominated by *Acer* and *Fraxinus* before collecting leaves in areas dominated by *Quercus* and *Tilia*. These actions would serve to reduce this potential source of urban runoff P to storm drainage systems.

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